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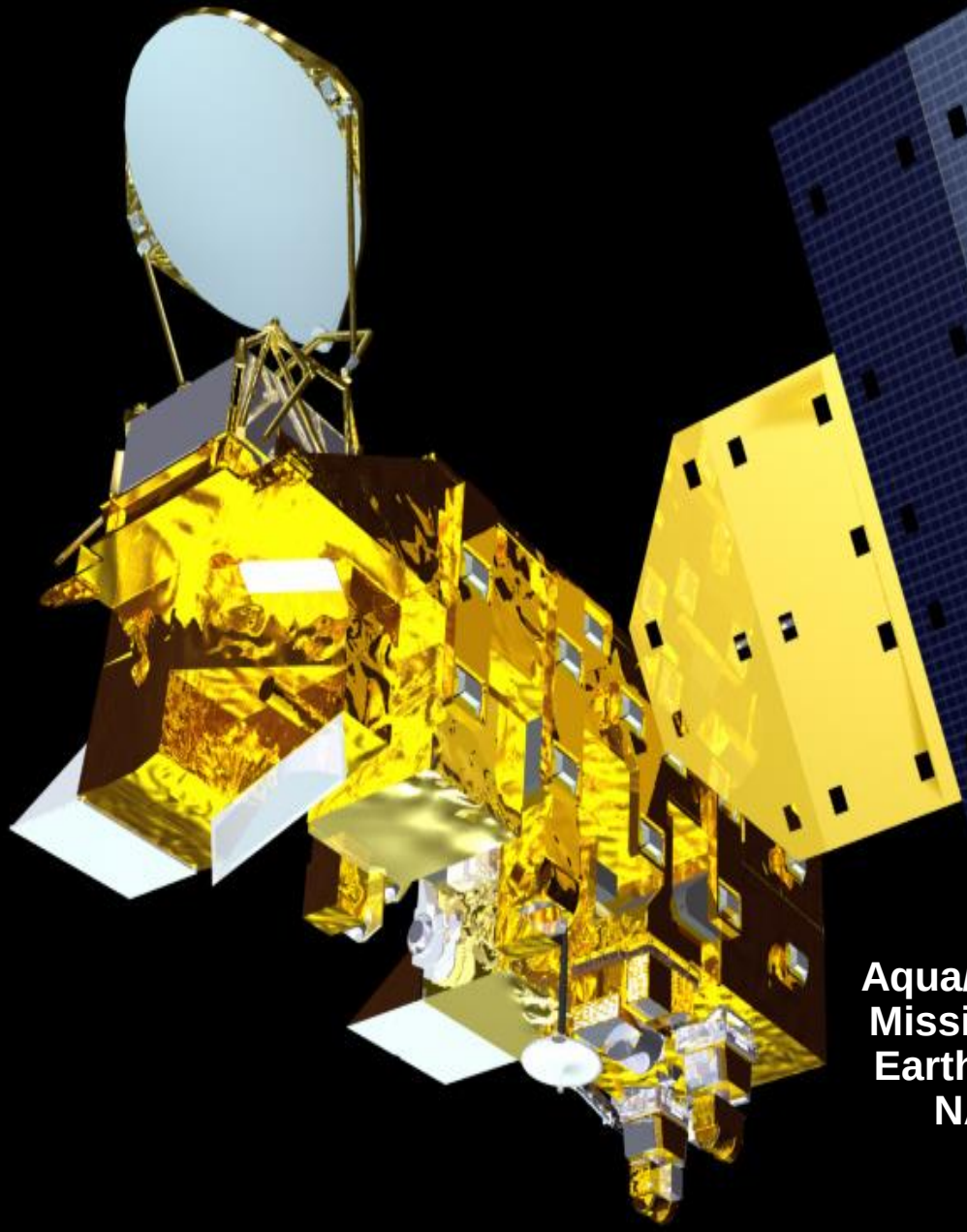
EOS Aqua



Mission Status at the Earth Science Constellation Mission Operations Working Group (MOWG) Meeting at GSFC

June 13, 2017

Bill Guit

Aqua/Aura Mission Director - Code 584/428
Mission Validation and Operations Branch
Earth Science Mission Operations Project
NASA/Goddard Space Flight Center

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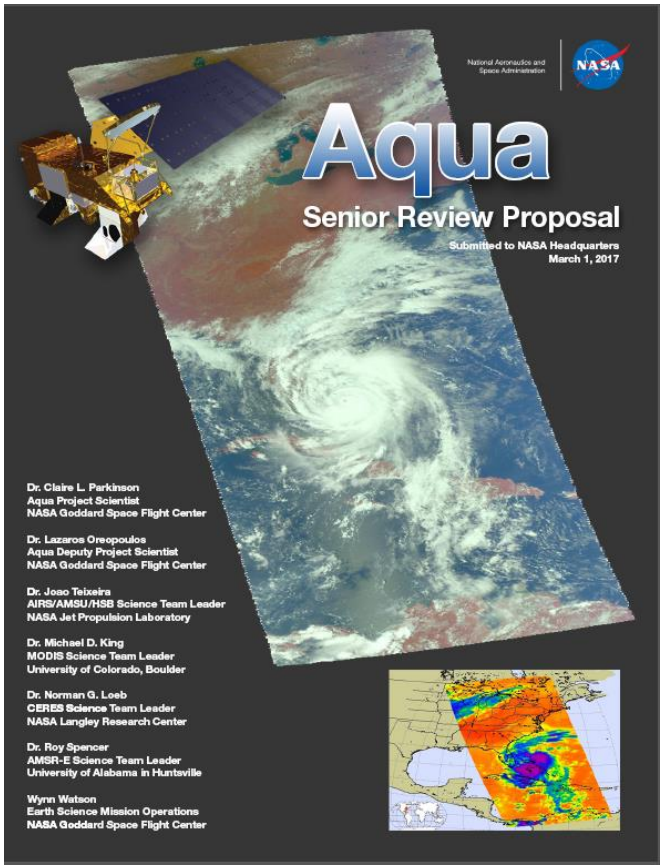
Topics

- **Mission Summary**
- **Spacecraft Subsystems Summary**
- **Recent & Planned Activities**
- **Inclination Adjust Maneuvers**
  - Spring 2018 **DRAFT** Calendar
  - Long-Term Plan (in EOS Flight Dynamics Presentation)
- **Propellant Usage & Lifetime Estimate**
- **End of Mission Plan**
- **Mission Summary**
- **Additional Slides:**
  - Orbit Maintenance Maneuvers
  - Conjunction Assessment High Interest Events
  - Ground Track Error & Mean Local Time History
  - Spacecraft Orbital Parameters Trends & Predictions

EOS Aqua Mission Summary

(Updates since September 2016 Meeting in Albuquerque, NM)

- **05/04/2002: Launch**
  - 6-Year Design Life
- **12/02/2008: End of Prime Mission Review**
- **06/22/2015: 2015 Mission Extension Senior Review Proposal Panel Report**
  - #1 Ranked Earth Science Mission
  - Mission extension through FY19
- **12/08/2015: End of AMSR-E Operations**
- **11/17/2016: A-Train PS Teleconference**
- **01/25/2017: ESMO Annual Review #10**
- **03/03/2017: Senior Review Proposal #6**
  - Reliability Estimates thru 2025
  - Consumables through 2022
- **05/04/2017: Aqua 15-Year Anniversary**



Aqua Spacecraft Subsystems

All subsystems configured to primary hardware

Changes since September 2016 MOWG Meeting are in blue

- **Command & Data Handling (CDH) – Nominal**
  - **Solid State Recorder (SSR) – only holds 2 orbits of data**
  - ***SSR Ops Error Anomaly (12/2/2007) – fully recovered 1/28/2009***
- **Communications (COMM) – Nominal**
- **Electrical Power System (EPS) – Nominal**
  - ***Array Regulator Electronics (ARE) 4A: 9/8/2004 – self-recovered***
    - » ***Re-occurred 1/11/2010 and 7/18/2013 (2 strings)***
  - ***ARE-1C: 11/8/2010 (1 string) and ARE-3A: 2/14/2012 (1 string)***
  - ***ARE-4C: 4/26/2015: Current fluctuations 8/21/2016 – 11/15/2016 and 12/23/2016 (2 strings)***
  - ***ARE-6C (10/20/2011) – Numerous current fluctuations since with last on 11/04/2015 (6 strings)***
  - ***ARE-5C power drop on 5/3/2016, partial recovery on 6/27/2016 (1 string)***
  - ***Summary: Estimated that Aqua has lost 13 strings of solar cells out of a total of 132 strings***
    - » ***Aqua continues to have significant power margin where the life limiting item is fuel***
  - ***Battery Cell Anomaly (9/2/2005)***
  - ***Solar Panel #8 Thermistor #6 Failure (8/3/2009)***
  - ***Solar Array Offset (Reported 11/17/09, Corrected 6/29/2010)***
- **Flight Software (FSW) – Nominal**
- **Guidance, Navigation & Control (GN&C) – Nominal**
- **Propulsion (PROP) – Nominal**
  - ***Dual Thruster Module (DTM-2) Heater Anomaly (9/8/2007)***
- **Thermal Control System (TCS) – Nominal**

Recent Activities
(October 2016 – 5/31/2017)

- **6 CARA High Interest Orbital Debris Events (HIEs): See charts 19 – 21**
  - **3 that required significant action**
    - » 3 RMM/DAMs PLANNED – 3 SELF-MITIGATED – 0 EXECUTED
  - **0 Planned routine DMUMs postponed/replanned and/or rescheduled**
- **1 Spacecraft Bus Anomaly (Ongoing ARE/Loss of SA strings):**
  - **08/21/2016 – 11/15/2016: ARE-4C Current fluctuations, again 12/23/2016**
- **2 Instrument Anomalies**
  - **09/24/2016: AMSU-A2 Power Off Anomaly – 11/29/2016: Deemed Non-recoverable**
  - **09/25/2016: AIRS Cooler-B Anomaly – Recovered 09/27/2016**
- **11 Spacecraft Delta-V Maneuvers:**
  - **7 Routine Drag Make-Up Maneuvers (DMUMs): All without yaw slews**
    - » 2016: 10/19 (#112), 11/16 (#113), 12/14 (#114), 2017: 1/12 (#115), 2/9 (#116), 4/13 (#117) and 5/10 (#118)
  - **4 Inclination Adjust Maneuvers (IAMs)**
    - » 2017: 3/1 (#52), 3/8 (#53), 3/22 (#54) and 3/29 (#55)
  - **0 Debris Avoidance Maneuvers (DAMs):**
- **8 Instrument Calibration Maneuvers: Monthly MODIS Lunar Calibrations**

Planned Activities

- **June 2017: Drag Make Up Maneuver (DMUM) # 119**
- **June 2017: Mission Extension Senior Review Proposal Panel Report**
- **July 2017: Updated Decommissioning & Lifetime Estimates for 2017**
- **December 2017: ESC/A-Train MOWG**
  - » Update propellant budget and decommissioning analysis
  - » FINAL 2018 Inclination Adjust Maneuver Schedule
- **- - - - - - - - - - - - - 2018 - - - - - - - - - - - - -**
- **January 2018: Flight Operations Annual Review (#11)**
- **March 2018: Updated End of Mission Plan (if necessary)**
- **Spring 2018: ESC/A-Train MOWG Meeting**
- **Spring 2018: Annual Inclination Adjust Maneuvers (DRAFT SCHEDULE)**
  - » 3/7 (#56), 3/14 (#57), 3/28 (#58), 4/11 (#59) & 4/18 (#60) Plus Backup 4/25
- **June 2017: ESC/A-Train MOWG**
- **- - - - - - - - - - Long-Term Plans - - - - - - - - -**
- Continue to improve Debris Avoidance Maneuver (DAM) responsiveness
- Automation of Routine Operations
- Possible Re-fueling Mission

Collision Risk Management Process Improvements

In response to the constantly increasing number of predicted close approaches with orbital debris and operational satellites (High Interest Events – HIEs – see slides 18 & 19) and anticipated updates to the DOD's Space Fence and size of the Space Catalog (20K → 200-270K)

ESMO is developing new ground system capabilities to autonomously identify and develop maneuver options to assist in Debris Avoidance Maneuver (DAM) planning (fully-automated end-to-end 24x7)

Collision Risk Management System (CRMS) capabilities include:

- **Automated debris avoidance maneuver planning**
- **User defined collision risk thresholds**
- **Maneuver optimization to address conjunctions with multiple secondary objects including repeating conjunctions**

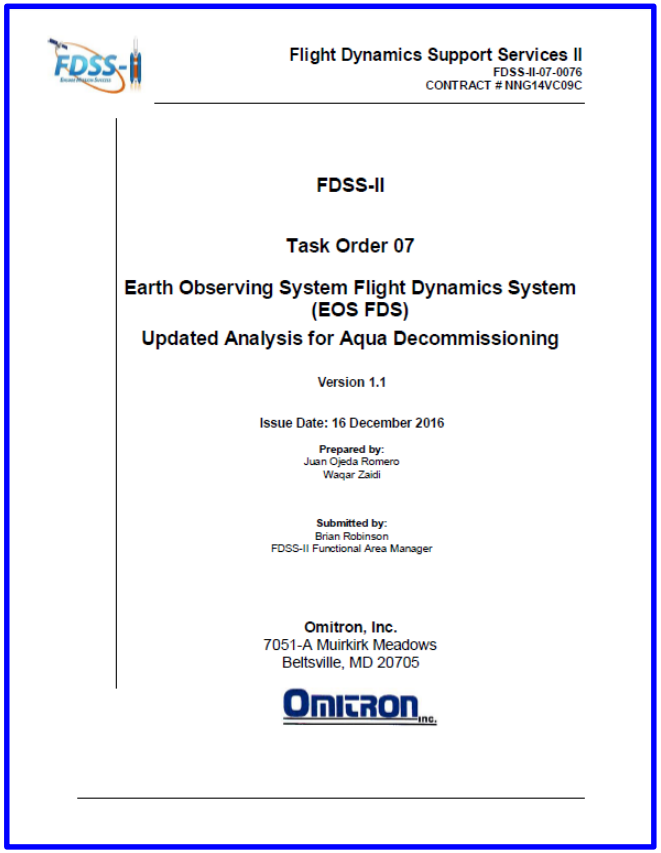
DRAFT Spring 2018
Aqua/Aura Inclination Adjust Plan

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
18 **Feb**	19	20	21	22	23	24
25	26	27	28	1March	2	3
4	5	6	7 **Aqua IAM #56**	8 **Aura IAM #53**	9	10
11	12	13	14 **Aqua IAM #57**	15 **Aura IAM #54**	16	17
18	19	20 Equinox	21 **Spring Break**	22 **Spring Break**	23	24
25	26	27 **Aura ID**	28 **Aqua IAM #58**	29 **Aura IAM #55**	30	31 **Aqua ID**
1 **April** **Easter**	2	3	4 **Easter Break**	5 **Easter Break**	6	7
8	9	10	11 **Aqua IAM #59**	12 **Aura IAM #56**	13	14
15	16	17	18 **Aqua IAM #60**	19 **Aura IAM #57**	20	21
22	23	24	25 **Aqua Back-up**	26 **Aura Back-up**	27	28
29	Golden Week in Japan					

Aqua Propellant Usage
(December 2016)

KEY: Updates since last MOWG Meeting in blue

- **2006: Initial Aqua lifetime fuel analysis**
- **2008: Detailed Aqua & Aura lifetime analyses**
  - Presented to A-Train MOWG and at Aqua EOPM Review
- **September 2012: Initial Aqua Decommissioning Plan**
  - Updated Lifetime Estimates
- **August 29, 2013: Updated Decommissioning Plan**
  - Updated Constellation Exit Plan
    - Safely exiting the Afternoon Constellation requires that Aqua's final apogee be at least two kilometers below the minimum perigee of the other constellation members (692 km target)
    - Perform orbit lowering maneuvers centered at apogee and perigee (pairs of maneuvers)
- **September 30, 2014: Updated Decommissioning Plan**
  - Updated definitive fuel usage and predicted solar flux levels
  - Updated propellant trends for IAMs & DMUMs
- **September 2015 Delayed to allow additional time to evaluate long-term plan and decommissioning maneuvers**
- **Summer 2016: Investigated more fuel efficient inclination adjust and retrograde maneuver options and various options for intending operations into mid-2020ies**
- **December 16, 2016: Updated Decommissioning Plan (V1.1)**
  - Updated definitive fuel usage & predicted solar flux levels
  - Updated propellant estimates for IAMs & DMUMs
- **Starting in 2017 the annual update will due to ESMO in July**
- **Final Plan due 60 days before start of decommissioning**



Flight Dynamics Support Services II
FDSS-II-07-0076
CONTRACT # NNG14VC09C

FDSS-II

Task Order 07

Earth Observing System Flight Dynamics System (EOS FDS)
Updated Analysis for Aqua Decommissioning

Version 1.1

Issue Date: 16 December 2016

Prepared by:
Juan Ojeda Romero
Waqar Zaidi

Submitted by:
Brian Robinson
FDSS-II Functional Area Manager

Omitron, Inc.
7051-A Muirkirk Meadows
Beltsville, MD 20705

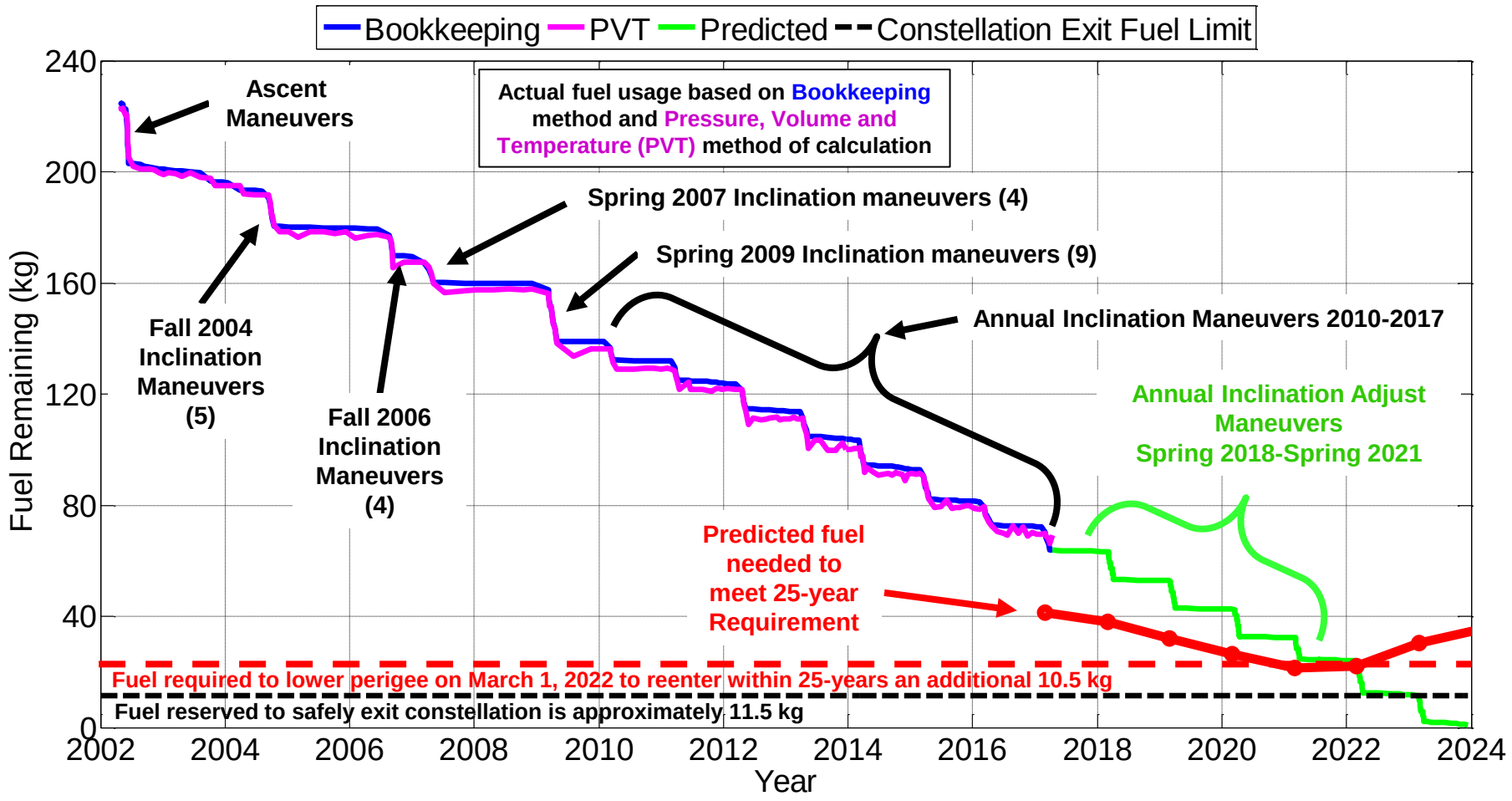
Aqua Remaining Fuel Estimate

(December 2016)

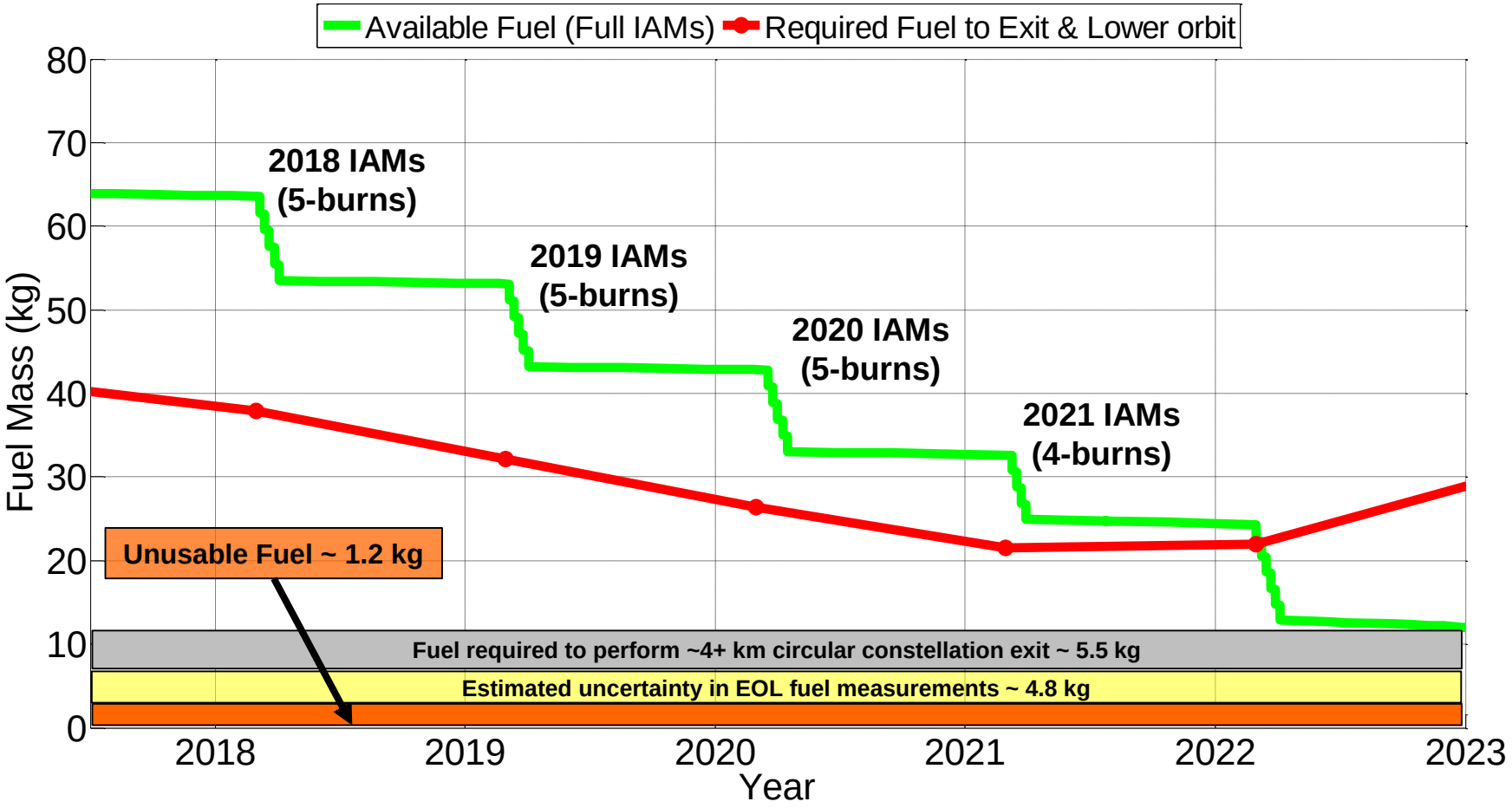
KEY: Updates since last MOWG Meeting in blue

- **Long-term orbit simulations were run for Aqua through 2023**
  - Used mean nominal Schatten solar flux predictions (August 2016)
  - Estimated the frequency of drag make-up maneuvers (DMUMs) to maintain Aqua's WRS-2 ground track requirements
  - Estimated the required number of annual inclination maneuvers (IAMs) for Aqua to maintain it's mean local time (MLT) requirement
  - Did not include potential debris avoidance maneuvers
  - Utilized FreeFlyer 6.7.2 which incorporated the solid earth tide model allowing greater accuracy for long term predictions of inclination, beta angle, and mean local time
- **Lifetime predictions for Aqua shows that the spacecraft will have sufficient fuel to maintain its current orbit within the Afternoon Constellation through the 2021 inclination adjust series of maneuvers.**
- **Exit from the constellation in March 2022 would likely be into a new operational orbit, not the decommissioning and passivation orbit, approximately 4+ km below the current ESC/A-Train operational orbit.**
- **Currently investigating various options to extend the potential Aqua mission life out into the 2025 time frame and possibly beyond.**
- **Aqua will hold sufficient fuel in reserve after exiting the constellation to lower perigee such that its reentry will meet the NASA 25-year reentry requirement.**

Fuel Usage: Actual & Predicted
(June 2017)



Fuel Usage:
Predicted Available & Required
(June 2017)



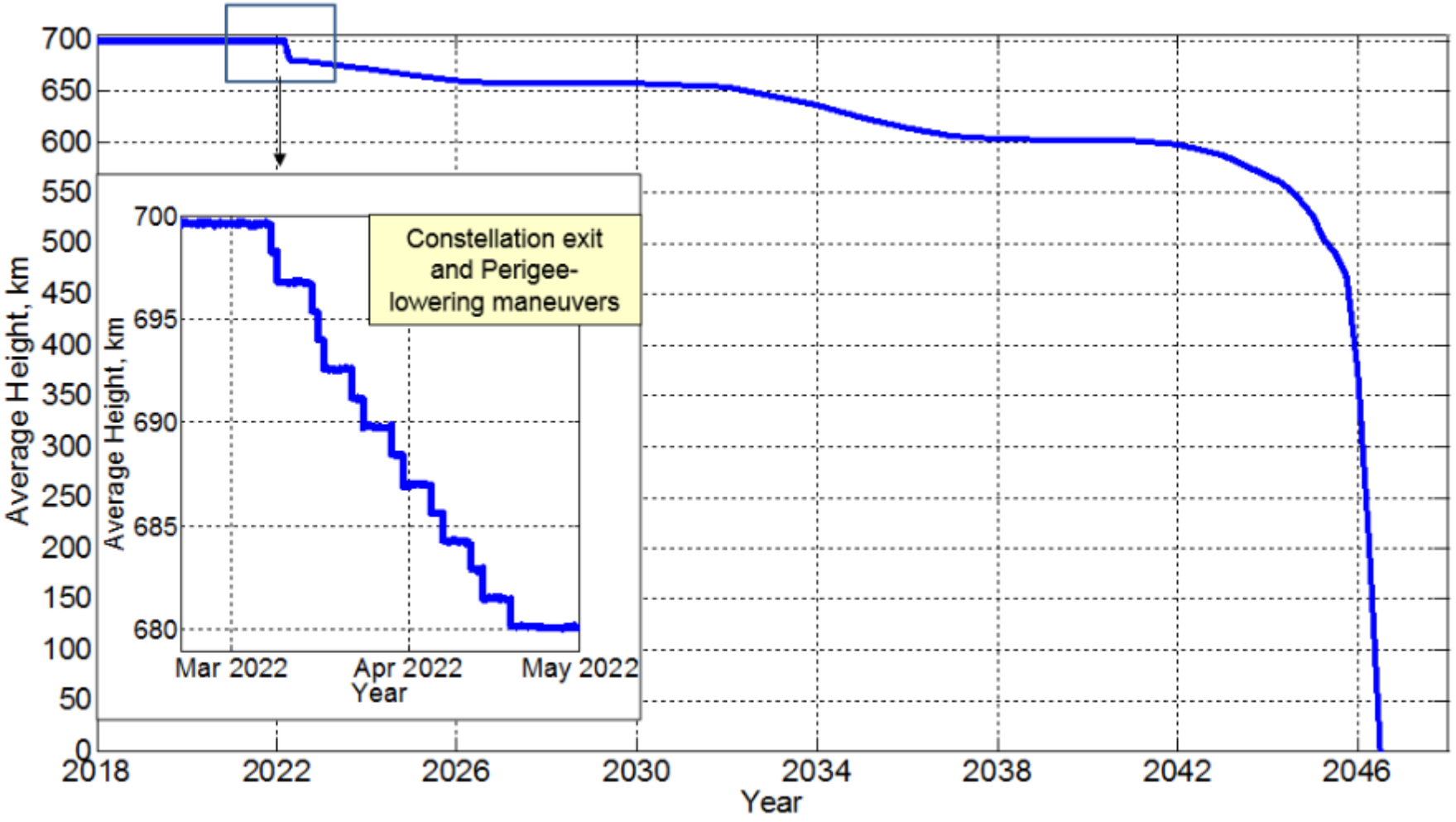
Debris Assessment Software

(December 2016)

KEY: Updates since last MOWG Meeting in blue

- **The Debris Assessment Software (DAS) was created by the Orbital Debris Office in Johnson Space Center and is the Agency standard for end of mission life analyses and lifetime estimations. (Current Version 2.0.2)**
- **DAS requires several inputs describing the spacecraft's mission:**
  - Launch date (05/04/2002)
  - Start inclination (98.2º)
  - Tumbling Area (47.80 m2)
  - Spacecraft dry mass (2854.6 kg)
  - End of Life unusable fuel (1.2 kg) and uncertainty (4.8 kg)
  - Area to Mass Ratio (0.01671 m2/kg) = Tumbling Area/Dry Mass + unusable + uncertainty
  - Start Apogee (702 km) – Apogee of orbit after final perigee lowering burn (04/19/2022)
  - Start Perigee (667 km) – Perigee of orbit after final perigee lowering burn (04/19/2022)
- **DAS outputs:**
  - If the mission is compliant with NASA requirements for limiting orbital debris.
  - A recommended apogee and perigee that will allow the spacecraft to reenter within a specific period and satisfy the NASA requirements.
- **Aqua has a waiver to the 30-years from launch requirement.**
- **Aqua will hold sufficient fuel in reserve to meet the 25-year requirement.**

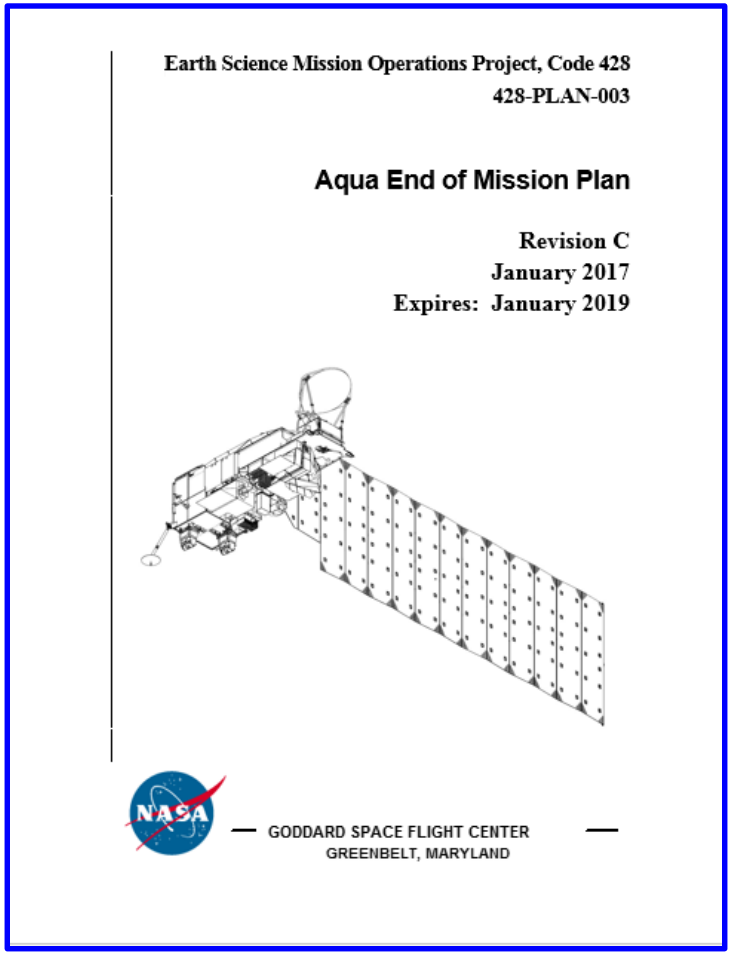
Aqua Orbital Decay



Aqua End of Mission Plan

KEY: Updates since last MOWG Meeting in blue

- **Initial draft February 2009**
- **"Interim" End of Mission Plan: May 2011**
  - Approved by NASA HQ July 2011
- **End of Mission Plan (Rev A): February 2013**
  - Updated Lifetime Estimates (09/2012)
  - Added Small Object Collision Assessment
- **End of Mission Plan (Rev B): June 2015**
  - Safely exit the A-Train Constellation (19 km)
  - Passivate to the extent possible for uncontrolled reentry
  - Aqua has five (5) approved waivers for passivation
    - » Pressurant Passivation
    - » Large Object Collision Probability
    - » Small Object Collision Probability
    - » Orbital Lifetime (30-Year)
    - » Re-entry Risk (Un-controlled)
  - **Waivers were approved in May 2013**
- **End of Mission Plan (Rev C): March 2017**
  - Latest Annual Lifetime Estimate (12/2016)
  - Includes ~4 km exit from A-Train in early 2022
  - Retrograde maneuver slews on reaction wheels
  - Currently in review cycle
- **Final produced 60 days before End of Mission**



Summary

KEY: Updates since last MOWG Meeting in blue

- **Spacecraft Status - GREEN**
- **Instrument Status - GREEN**
  - **AIRS, AMSU, CERES & MODIS:**
    - » CERES and MODIS: Nominal Operations
    - » 09/24/2016: AMSU-A2 Anomaly – currently no further recovery attempts are planned
    - » 01/31/2017: JPL AMSU-A2 Anomaly Closeout Review
  - **HSB: Survival Mode since 2/5/2003**
  - **AMSR-E: Powered Down 03/03/2016**
- **Data Capture/L0 Processing Status – GREEN**
  - SSR Data Capture April 2017: 100%
  - SSR Data Capture to 04/30/2017: 99.9785994%
- **Data Latency – Excellent**
- **Ground Systems – Responding to new security requirements and upgrades to obsolete hardware or COTS systems, as required**
  - Automation Effort: CDR 2/2013, Phase II CDR 1/29/2014, Delivery 2/2/2015
  - Phase II: R2.6.1 Development & Testing 9/1/2015 – 12/16/2016 (COMPLETE)
  - EOS Automation (EA) ORR with Eclipse 20.01 mid-July (20.01 ORR was 2/9)

Additional Slides

Orbit Maintenance Maneuvers
Conjunction Assessment High Interest Events
Ground Track Error & Mean Local Time History
Spacecraft Orbital Parameters Trends & Predictions

Orbit Maintenance

KEY: Updates since last MOWG Meeting in blue

- **<u>Mission Requirement</u>: Perform Drag Make-Up Maneuvers (DMUMs) to maintain Aqua's ground track error (GTE) with respect to the World Reference System (WRS-2) within +/-10 Km at the Descending Node**
  - Changed from +/-20 Km with DMUM #19 (1/12/05)
  - 118 DMUMs have been performed to date (Last #118 on 5/10/2017, Next #119: June 2017)
  - Variation in performance from –20.9% (cold) to +24% (hot) #108 was 20.9% COLD
- **<u>Control Box Excursions</u>: Since 2012 there have been 6 Control box Excursions**
  - **4 on +10km front-side: 11/4/12 to 11/14/12, 10/23/13 to 10/24/13 and 3/6/14 to 3/10/14**
    - 03/16/2015 to 04/02/2015
  - **2 on -10km back-side: 11/07/13 to 12/14/13 (Emergency DAM on 10/24 and DAM on 11/28)**
    - 04/02/2016 to 05/07/2016
- **<u>Mission Requirement</u>: Perform inclination adjust maneuvers (IAMs) to maintain the Mean Local Time (MLT) as measured at the Ascending Node between 1:30 and 1:45 MLT (Mission Goal starting in 2011: 13:35:45 +/- 45 seconds)**
  - **55 Inclination Adjustment Maneuvers (IAMs) performed to date**
    - Fall 2003 (1), Spring 2004 (1), Fall 2004 (5), 2005 (NONE)
    - Fall 2006 (4 of 6 - cancelled final 2 burns), Spring 2007 (4 - interrupted 2-weeks),
    - Spring 2008 – NONE per special request from PARASOL
    - Spring 2009 (9), Spring 2010 (3), Spring 2011 (3), Spring 2012 (4)
    - Spring 2013 (4 with #3 being delayed 1-week), Spring 2014 (4), Spring 2015 (5)
    - Spring 2016 (all 4 IAMs completed, one had to be re-scheduled)
    - Spring 2017: 3/1 (#52), 3/8 (#53), 3/22 (#54) and 3/29 (#55)

Aqua Conjunction Assessment High Interest Events (HIEs) – 2016

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2016	2	3	3	2	5	1	2	0	1	1	1	0	21
Tier 1	0	0	3	1	1	0	0	0	0	0	0	0	5
Tier 2	2	2	0	0	3	1	2	0	1	1	0	0	12
Tier 3	0	1	0	1	1	0	0	0	0	0	1	0	4
Tier 4	0	0	0	0	0	0	0	0	0	0	0	0	0

2013: 28 CARA HIEs – 9 required significant action
2014: 34 CARA HIEs – 14 required significant action
2015: 26 CARA HIEs – 16 required significant action

Tier 1 – Notify (email/phone), Tier 2 – Conduct Briefing, Tier 3 – Plan Maneuver, Tier 4 – Execute Maneuver

2016 thru 12/31/2016: 21 CARA HIEs – 4 that required significant action (Tiers 3 & 4)

1. 02/26/2015: CA vs. 35970 at 05:25:29 GMT – DAMs planned, self-mitigated (T3)
2. 04/09/2016: CA vs. 10144 at 18:00:00 GMT – DAMs planned, self-mitigated (T3)
3. 05/13/2016: CA vs. 40578 at 02:28:11 GMT – DAMs planned, self-mitigated (T3)
4. 11/11/2016: CA vs. 36894 at 14:11:26 GMT – DAMs planned, self-mitigated (T3)
5. No CARA HIEs in December

2016 Aqua Summary: 4 DAMs Planned, 0 DAMs Executed, 4 DAMs that self-mitigated

0 Routine maneuvers were postponed/replanned and/or rescheduled (Tier 4s)

Aqua Conjunction Assessment High Interest Events (HIEs) – 2017

(October 2016 – 5/31/2017: 6 CARA HIEs – 3 Required Significant Action)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2017	1	2	1	0	0								4
Tier 1	1	1	0	0	0								2
Tier 2	0	0	0	0	0								0
Tier 3	0	1	1	0	0								2
Tier 4	0	0	0	0	0								0

2013: 28 CARA HIEs – 9 required significant action
2014: 34 CARA HIEs – 14 required significant action
2015: 26 CARA HIEs – 16 required significant action
2016: 21 CARA HIEs – 4 required significant action

Tier 1 – Notify (email/phone), Tier 2 – Conduct Briefing, Tier 3 – Plan Maneuver, Tier 4 – Execute Maneuver

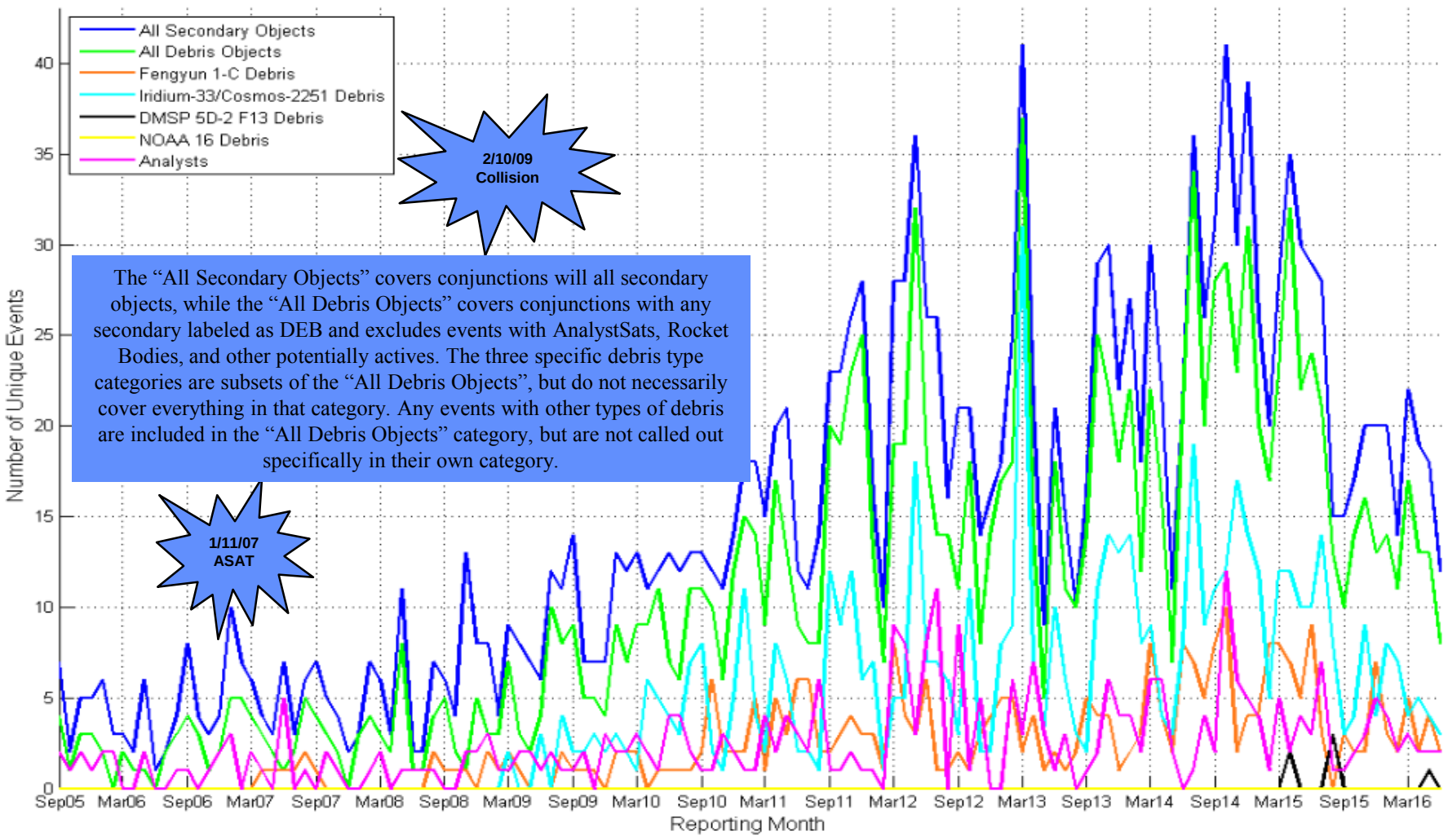
2017 thru 03/31/2017: 4 CARA HIEs – 2 that required significant action (Tiers 3 & 4)

1. 02/26/2017: CA vs. 81514 at 13:55:27 GMT – DAMs planned & approved, new tracking dropped risk (T3)
2. 03/04/2017: CA vs. 33503 at 10:48:40 GMT – DAMs planned, self-mitigated (T3)

2017 Aqua Summary: 2 DAM Planned, 0 DAMs Executed, 2 DAM that self-mitigated

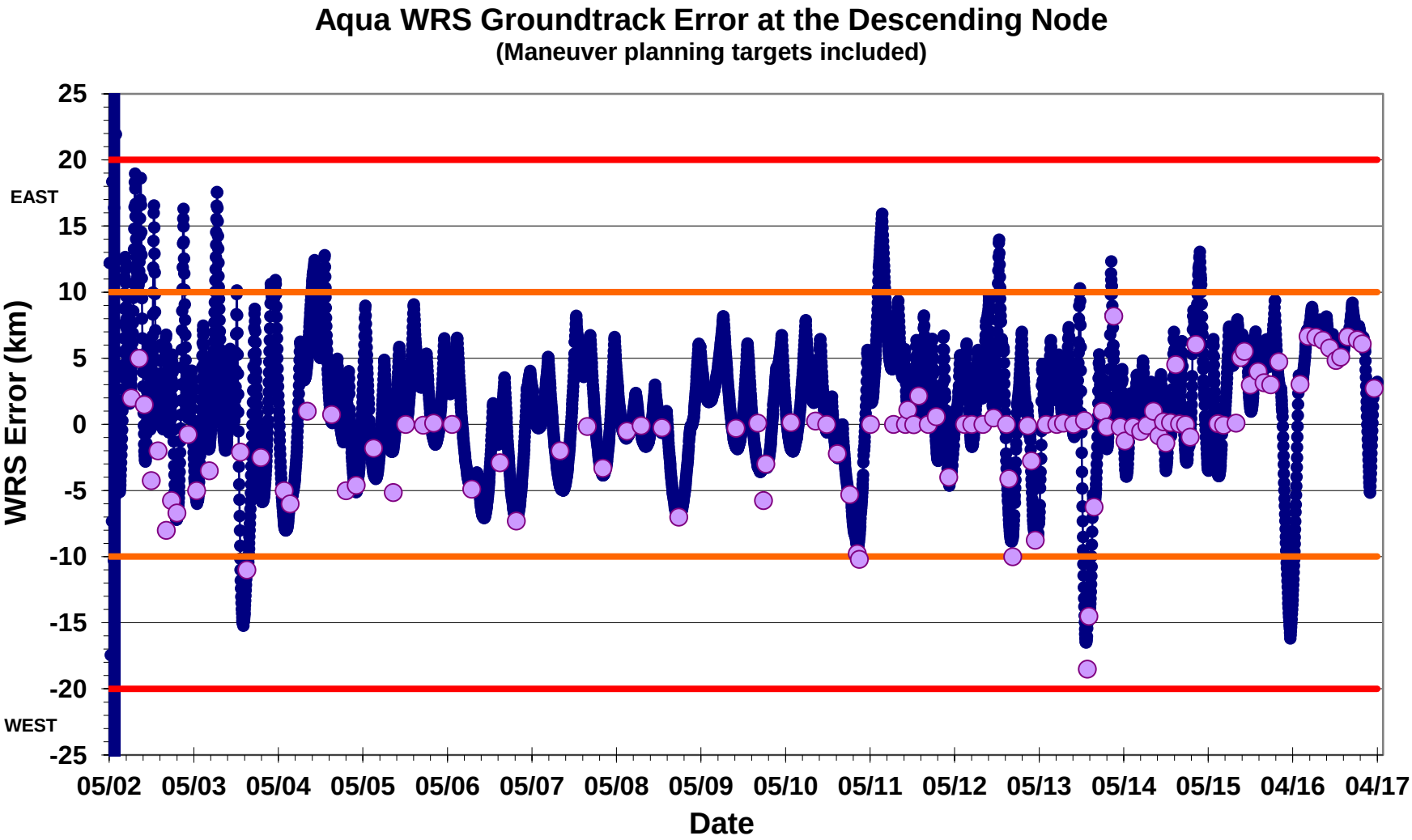
0 Routine maneuvers were postponed/replanned and/or rescheduled (Tier 4s)

Aqua Conjunction Assessment Statistics
(September 2005 thru June 2016)

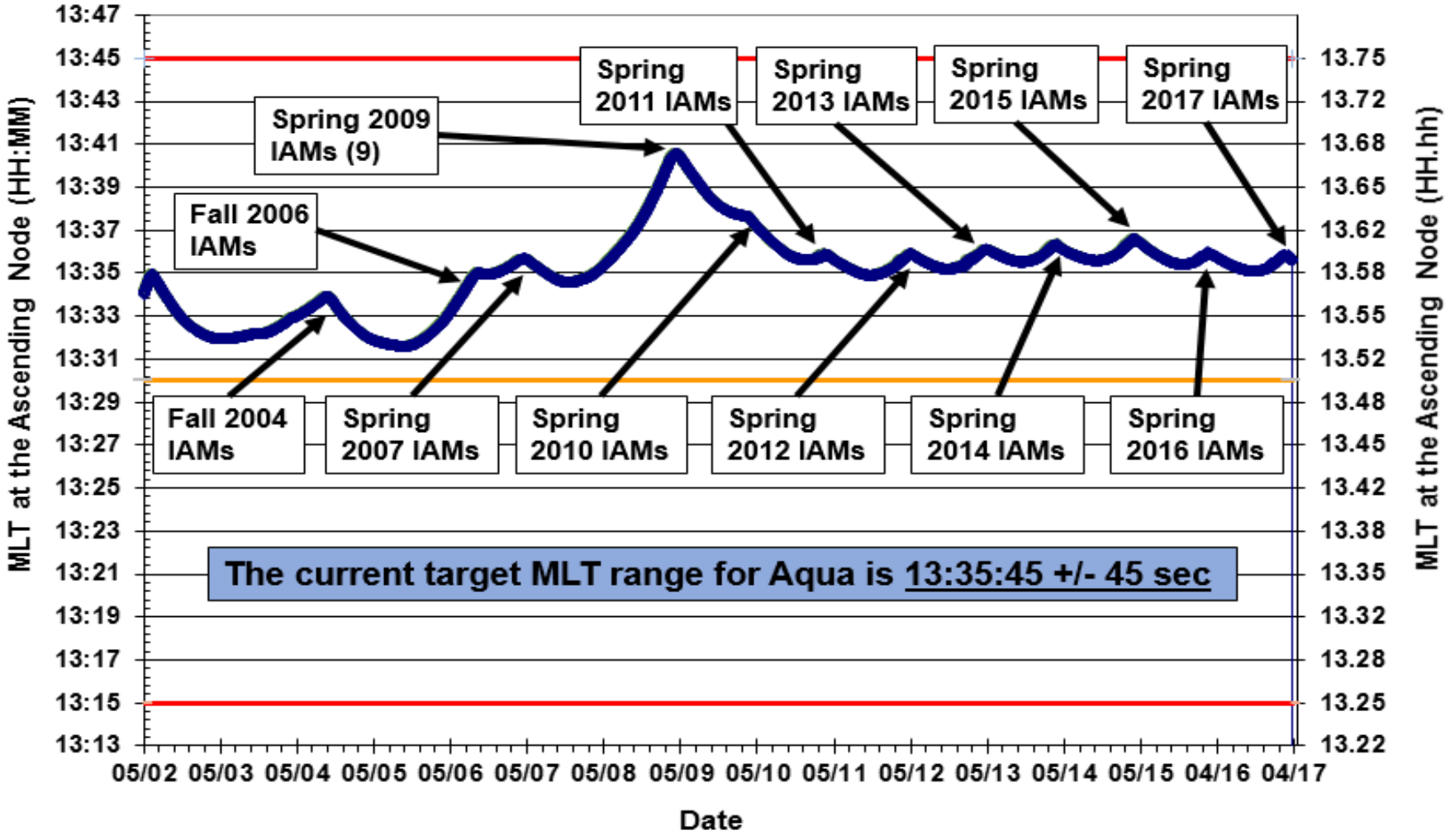


WRS Ground Track Error (GTE)

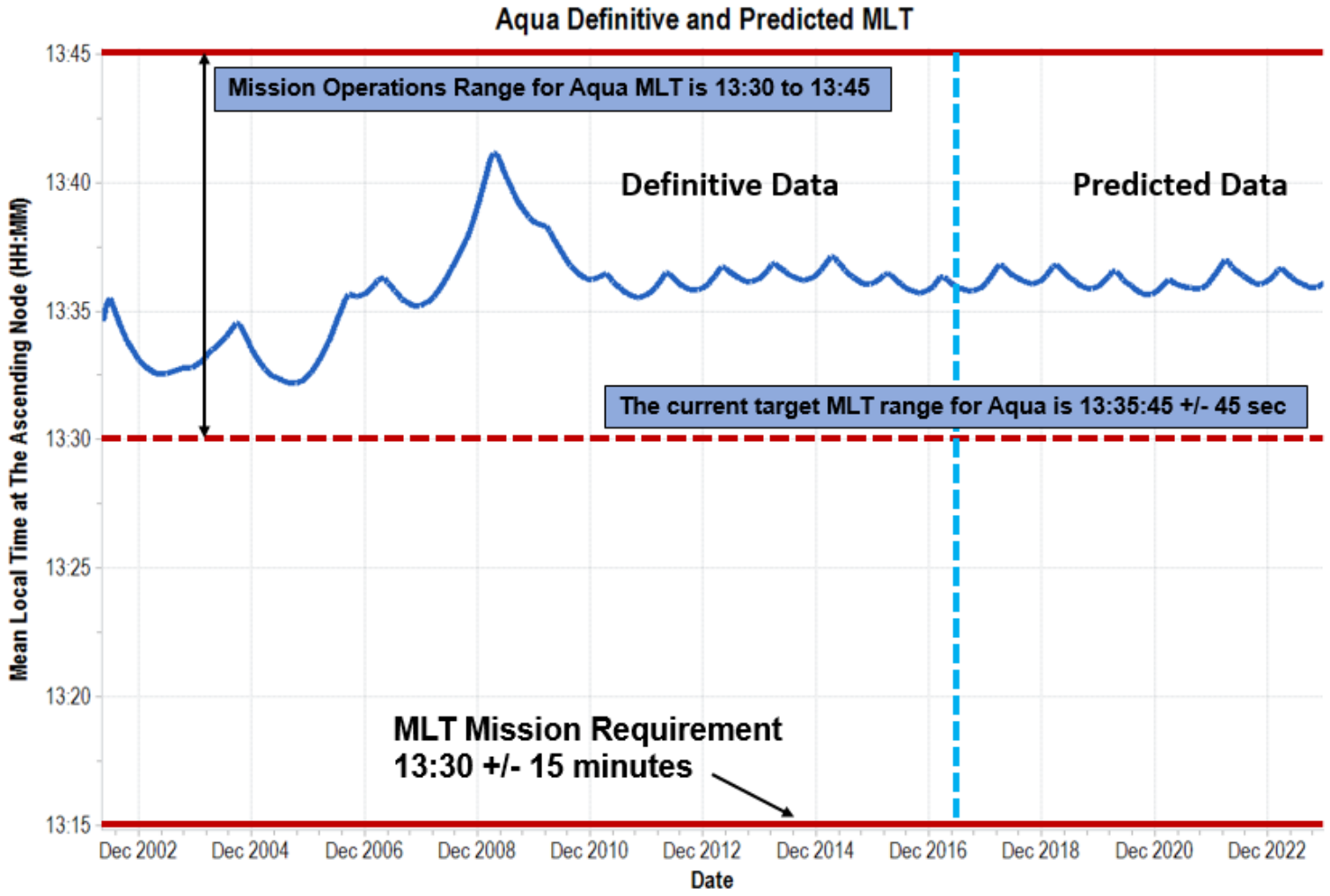
(As of May 2, 2017)



Aqua Averaged MLT @ Ascending Node
(As of May 2, 2017)



Aqua MLT @ Ascending Node
(as of May 2, 2017)

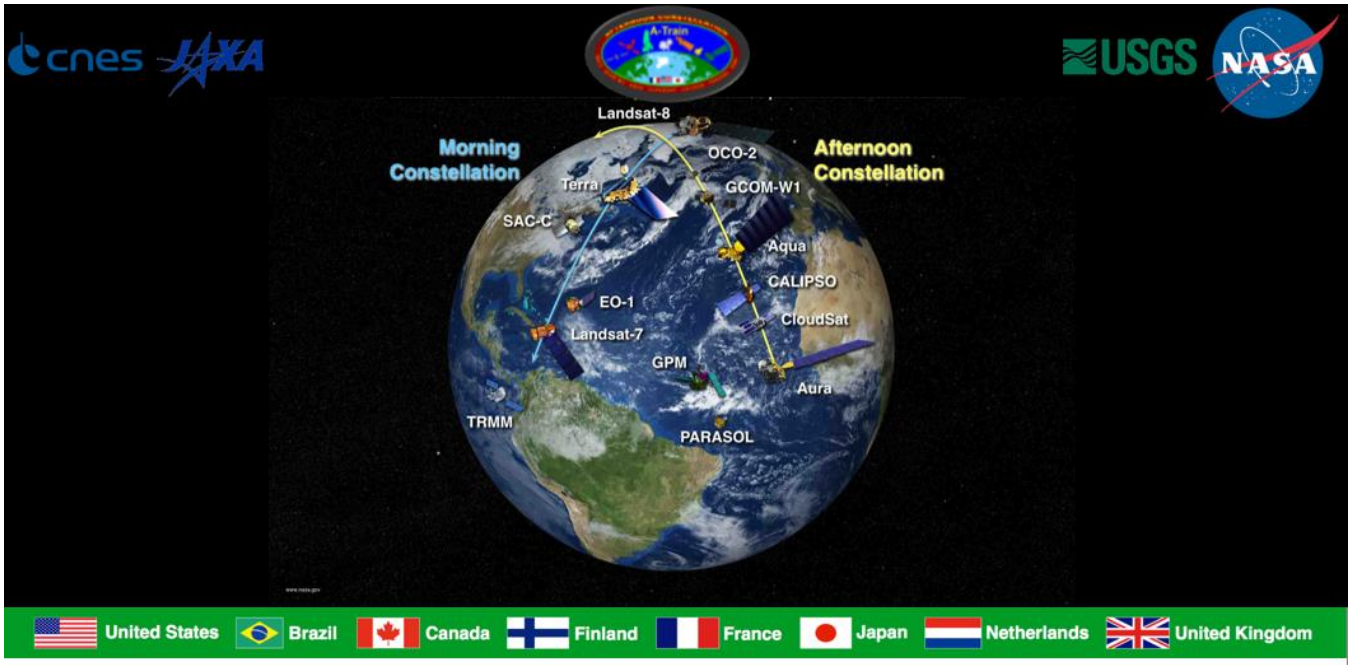


Inclination/MLT Maintenance
(May 2017)

KEY: Updates since last MOWG Meeting in blue

- EOS Flight Dynamics has analyzed and updated the nominal inclination schedule that ensures Aqua's mean local time of the ascending node (MLTAN) remains within the current target range.
  - The current target MLTAN range for Aqua is 13:35:45 +/- 45 sec.
  - Aqua's current mission MLTAN requirements are {13:30:00 - 13:45:00}
  - Aqua's performance for the 2017 inclination series was -0.64% (COLD)
- Proposed long-term inclination adjust plan is predicted to keep Aqua within the target MLTAN range.
  - Nominal case schedules Aqua inclination maneuvers that are not on weeks starting with Easter. The maneuvers are not currently centered around the ideal dates.
  - Currently investigating fuel-efficient Retrograde Maneuver Options
- Will re-visit/re-validate the long-term plan after each series of annual inclination adjust maneuvers.
- See EOS Flight Dynamics Presentation for long-term plan.

Inclination/MLT Maintenance
(Long-Term Plan)



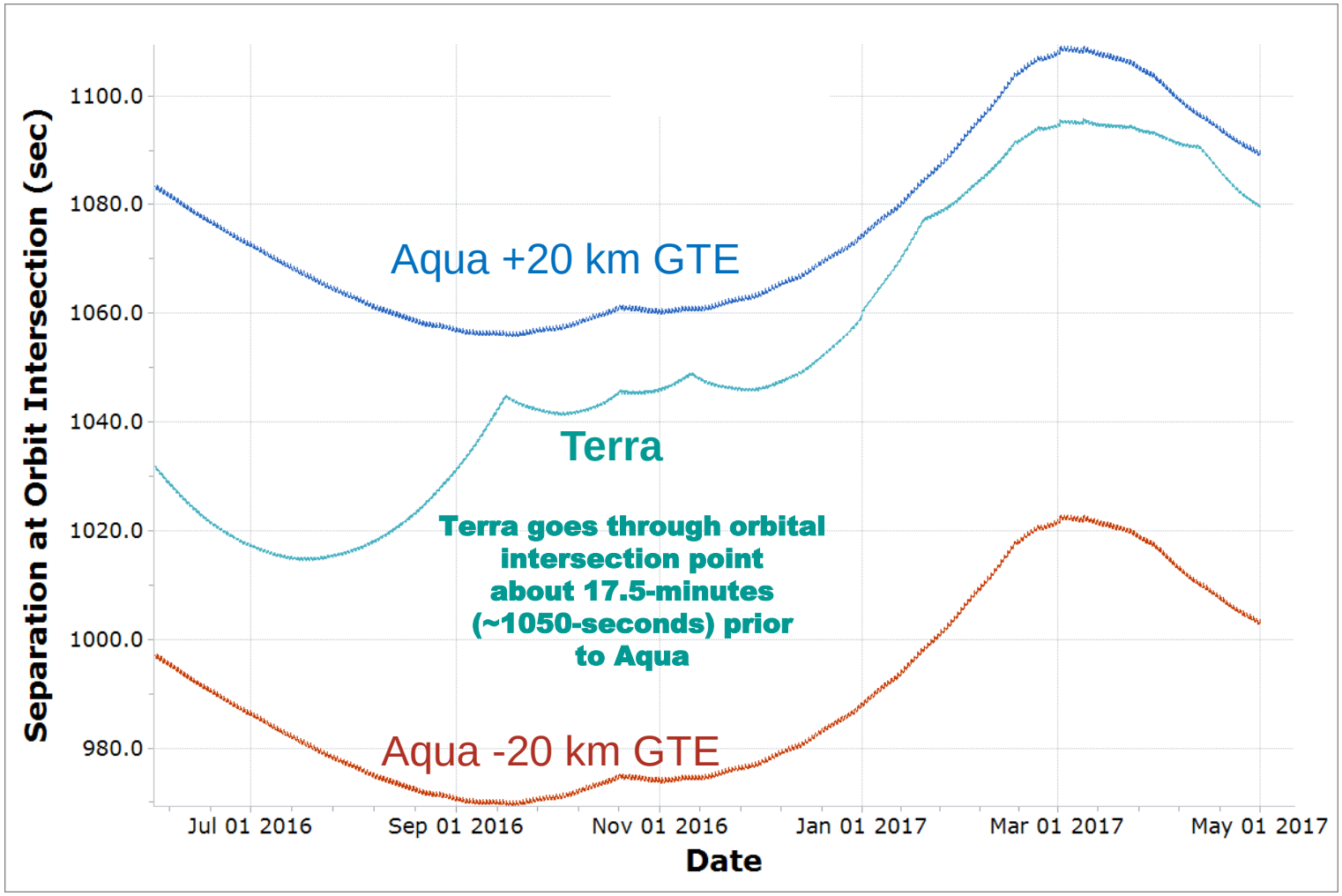
International Earth Science Constellation
Mission Operations Working Group
June 13-15, 2017

Aqua/Aura Spring 2017 IAM Series

Thomas Noyes and Shane Stezelberger
EOS FDS, esmo-eos-fds@lists.nasa.gov, +1.301.614.5050

Terra to Aqua Phasing

(as of May 2, 2017)




Mission
Operations
Project
GSFC
ESMO
NASA
Earth
Science


NASA

Questions